Advances in Entry Modeling for Impact Risk Assessment

IAA Planetary Defense Conference
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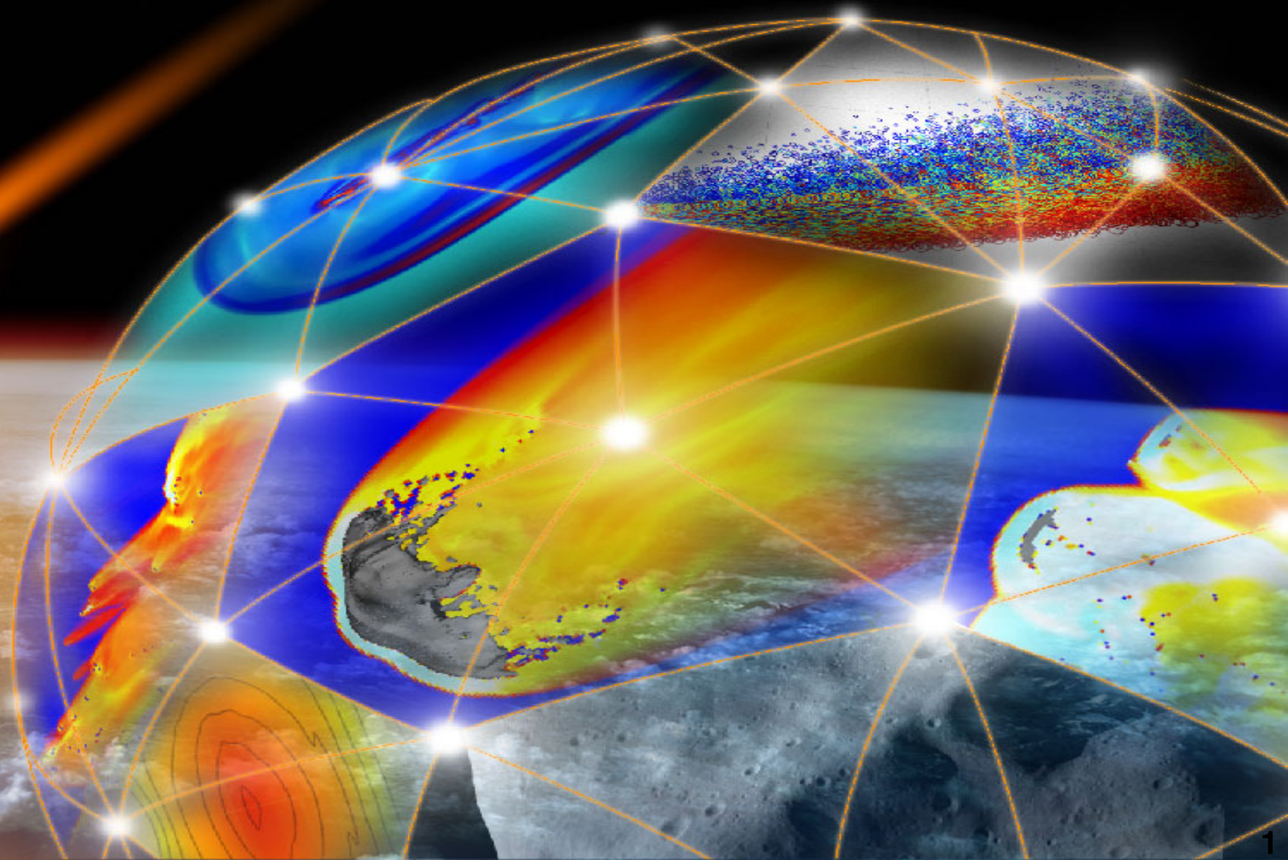
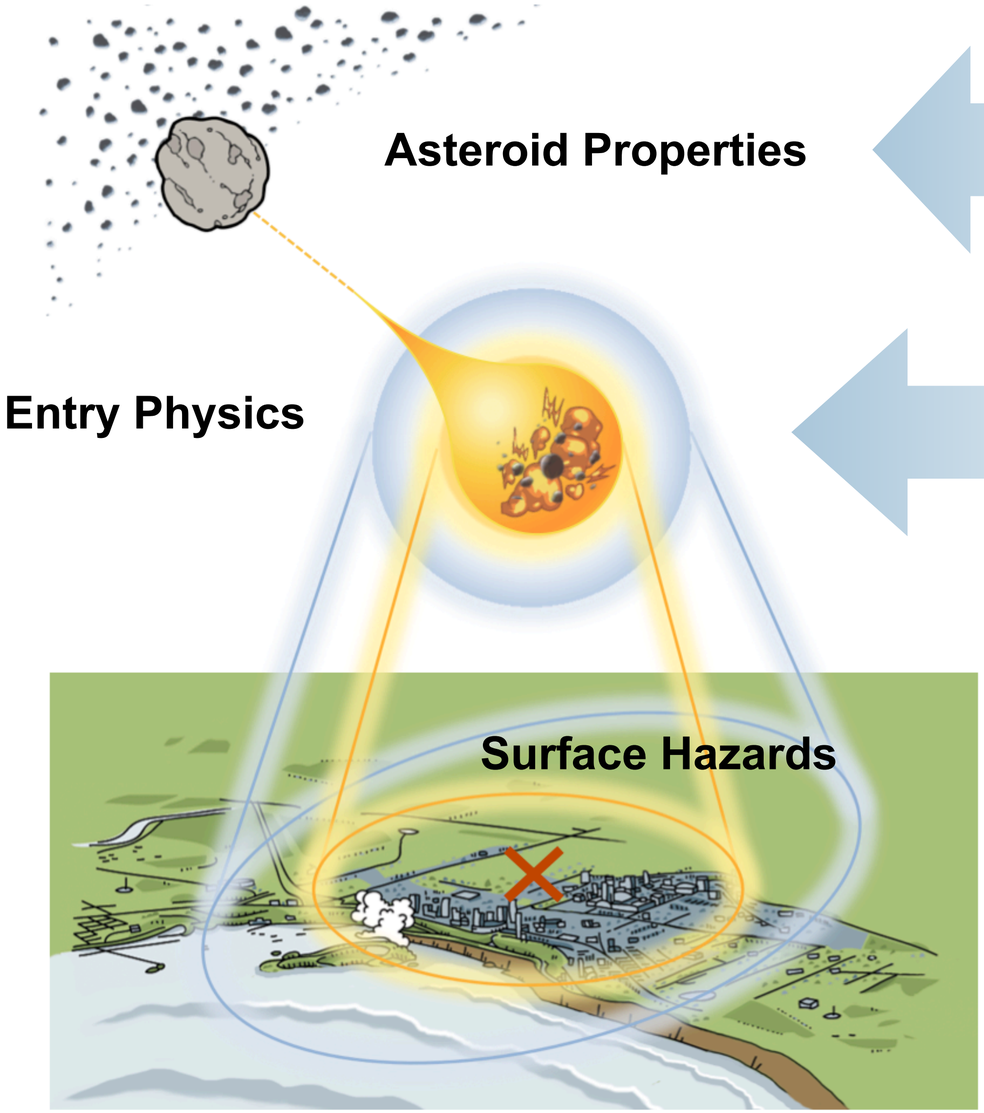


Asteroid Threat Assessment Project (ATAP)



Characterization
- Measurements
- Inference
- Data aggregation
- Property database website

Entry Simulations & Testing
- Flow modeling and radiation
- Ablation modeling and testing
- Fragmentation and break-up

Hazard Simulations
- 3D blast simulations
- Impact crater simulations
- Tsunami simulations
- Thermal radiation models
- Global effects

Probabilistic Risk Assessment
- Analytic physics-based entry and damage models
- Probabilistic Monte Carlo simulation using uncertainty distributions

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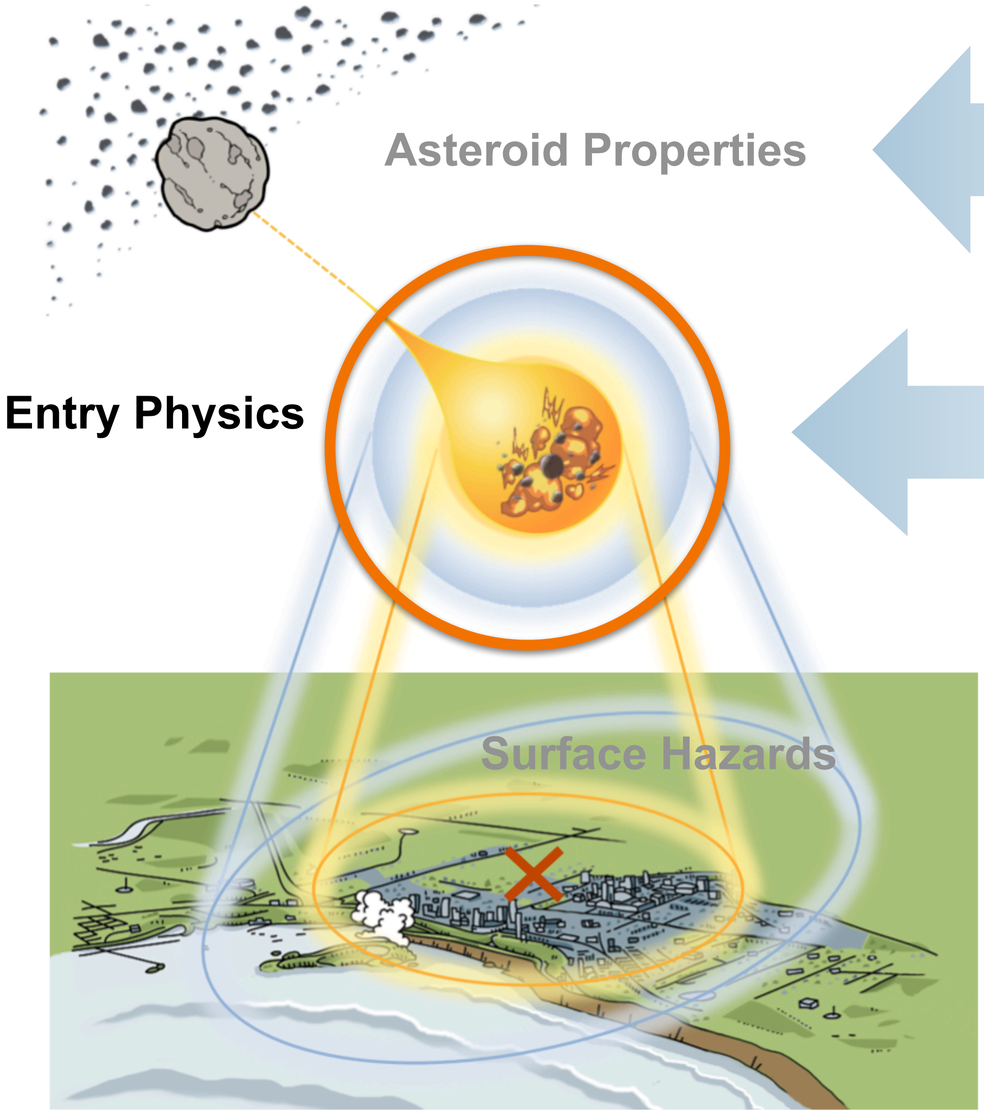

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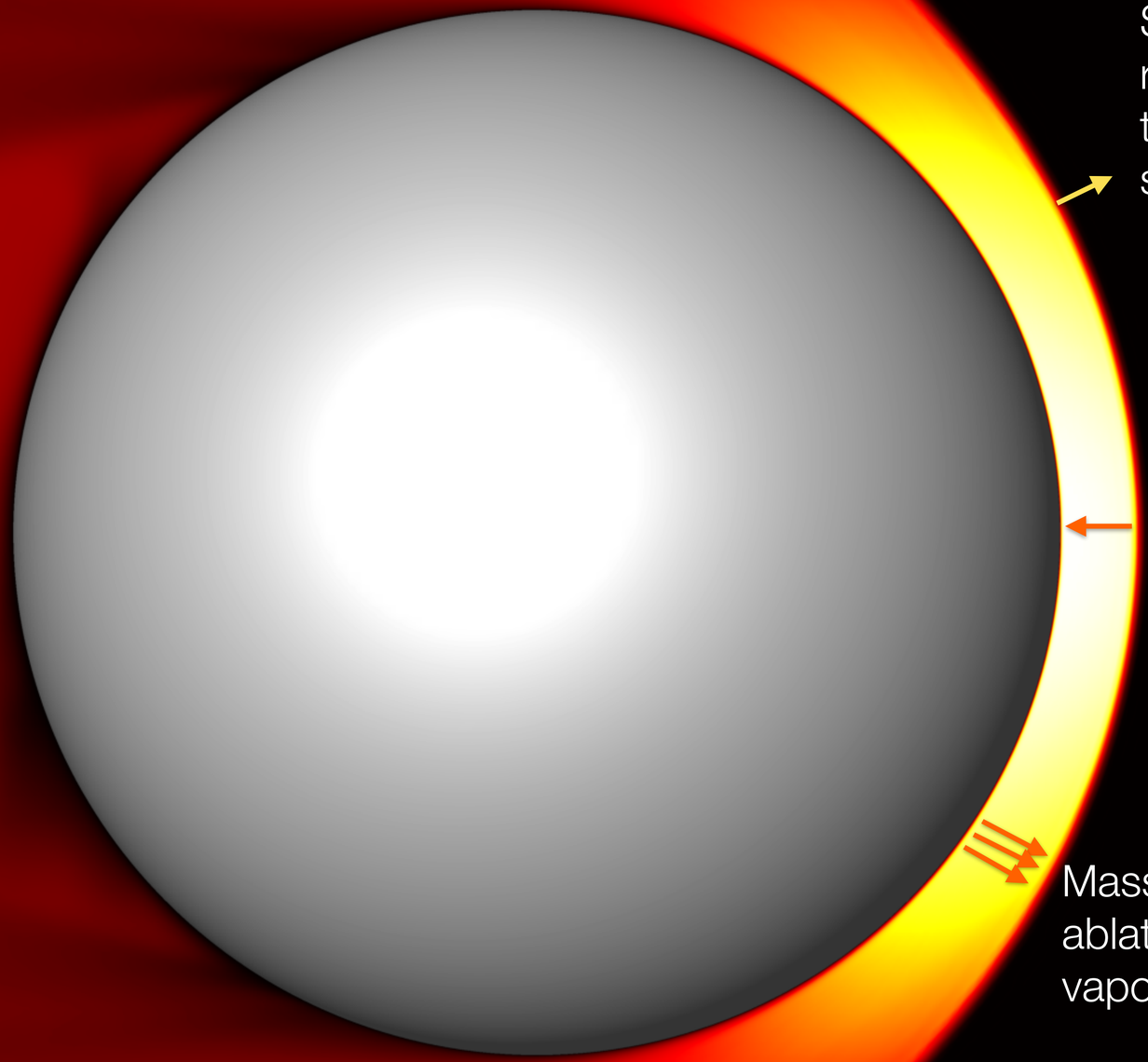
Outline:

- Flow modeling and radiation
  - Simulation approach
  - Validation of bolide spectra simulations
- Current state-of-the-art and future work

Flow Modeling and Radiation



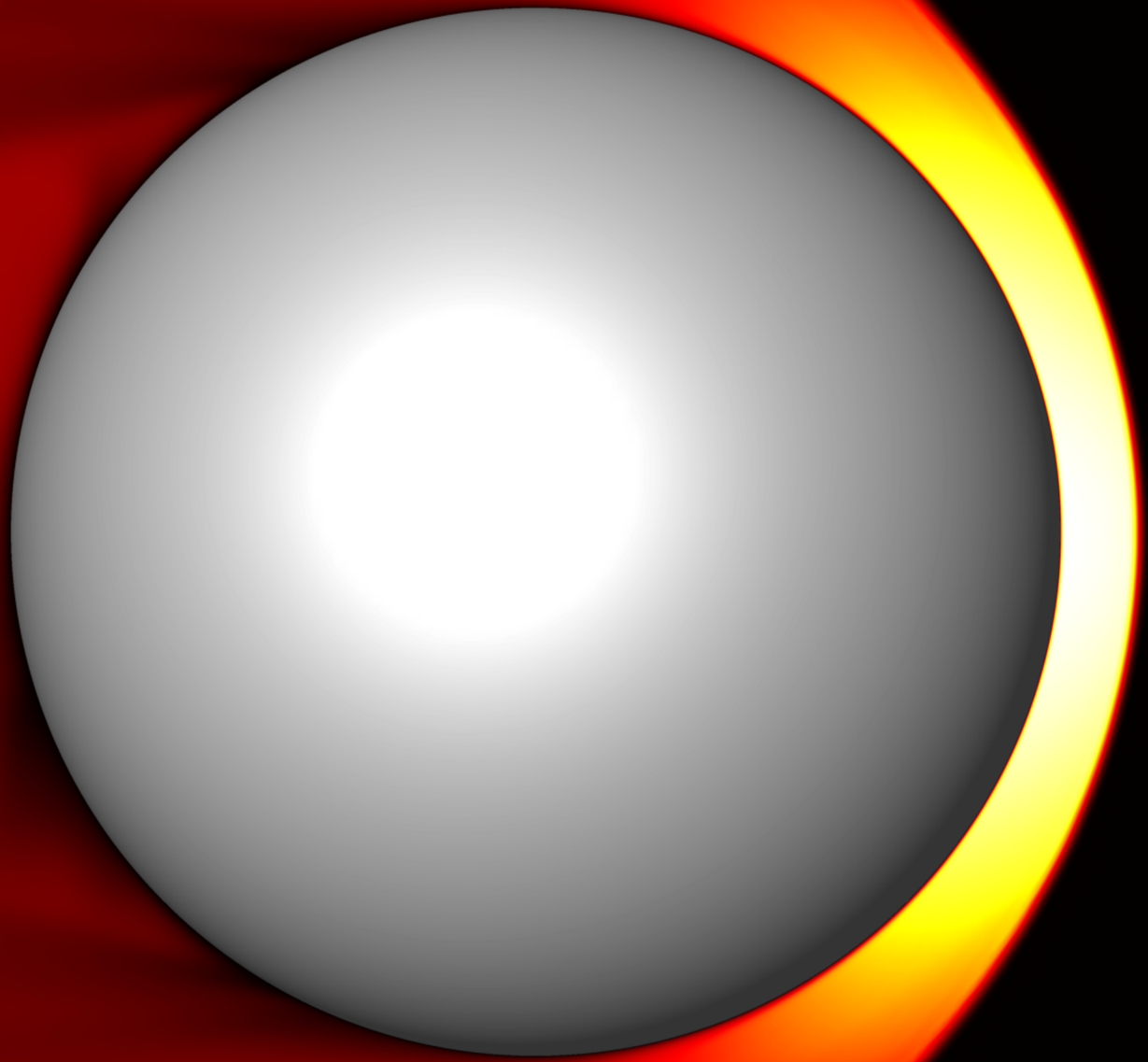
Shock layer radiates out to the surroundings

Extreme radiative heat flux to the surface

Massive ablation from vaporization

Heated ablation and high-temperature air species products radiation, producing observed light, spectra, and thermal radiation

Flow Modeling and Radiation

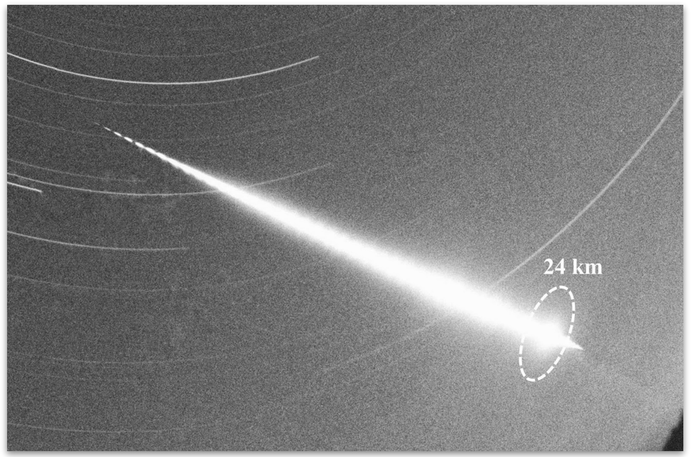


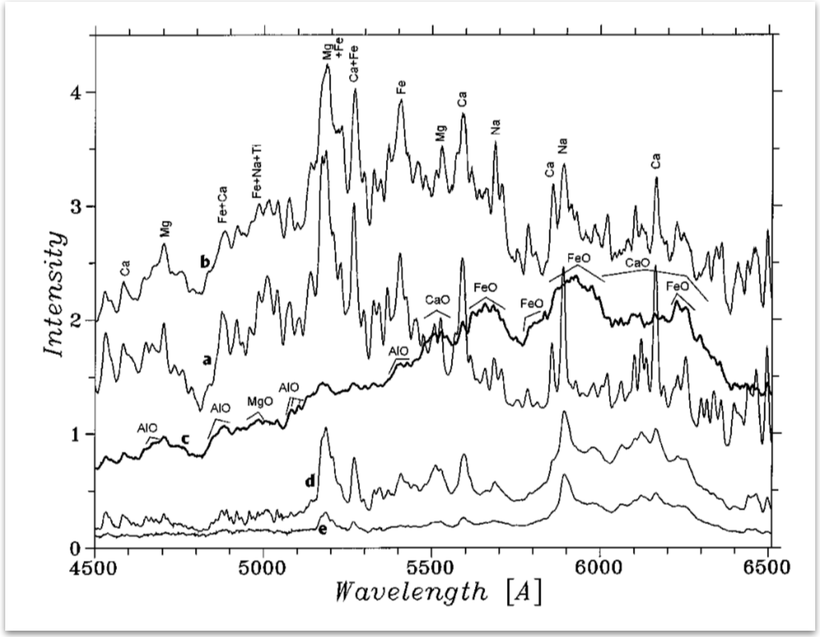
- LAURA hypersonic CFD code used for all simulations
- HARA radiation transport code is used to compute spectral radiance
- Vaporization of the meteoroid modeled using steady-state equilibrium assumption
- Melting not modeled
- Details on the computational approach can be found in Johnston et al., Icarus, 2018

Benesov Validation Study

- Computational approach produces detailed spectra over an arbitrary wavelength range
- The Benesov bolide, which occurred over the Czech Republic on May 7, 1991, is one of the few meter class events for which detailed spectra were captured
  - ➡ Provides an invaluable source of validation data for entry models being applied to impact assessments

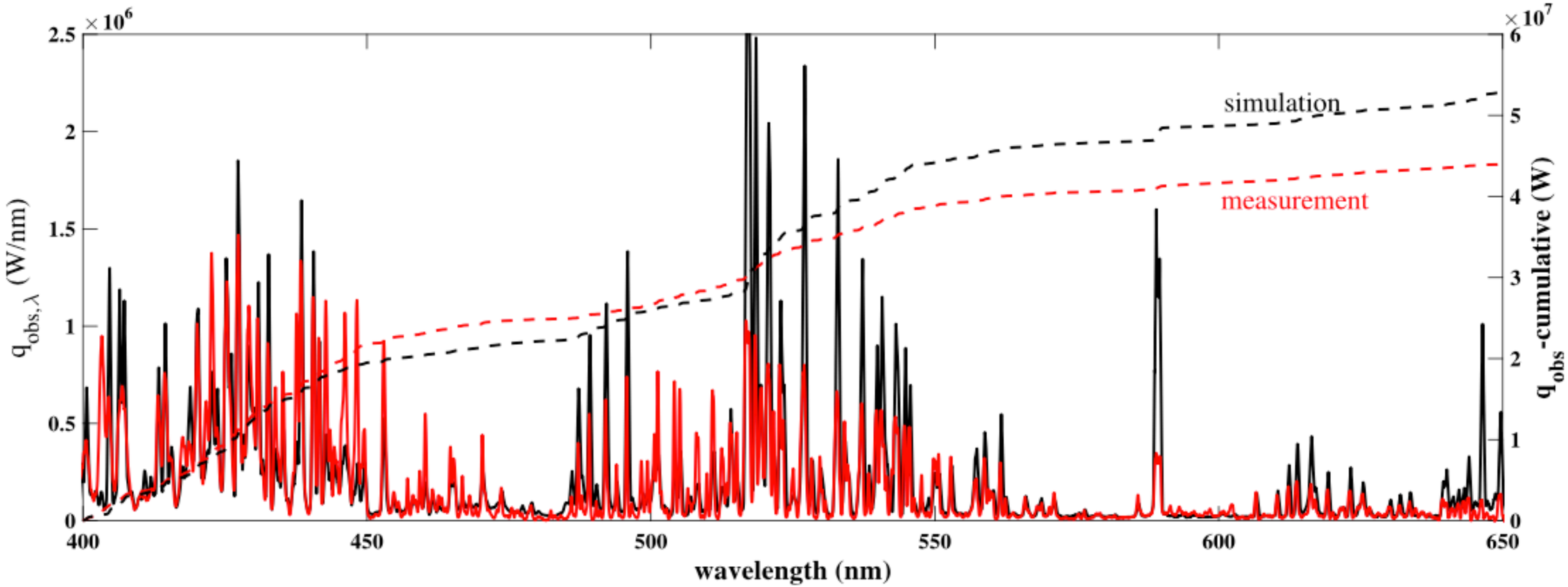
- Detailed computations were performed for a 0.8m sphere
  - ➡ Velocity = 20 km/s
  - ➡ Altitude = 47 and 57 km
  - ➡ LL chondrite elemental composition



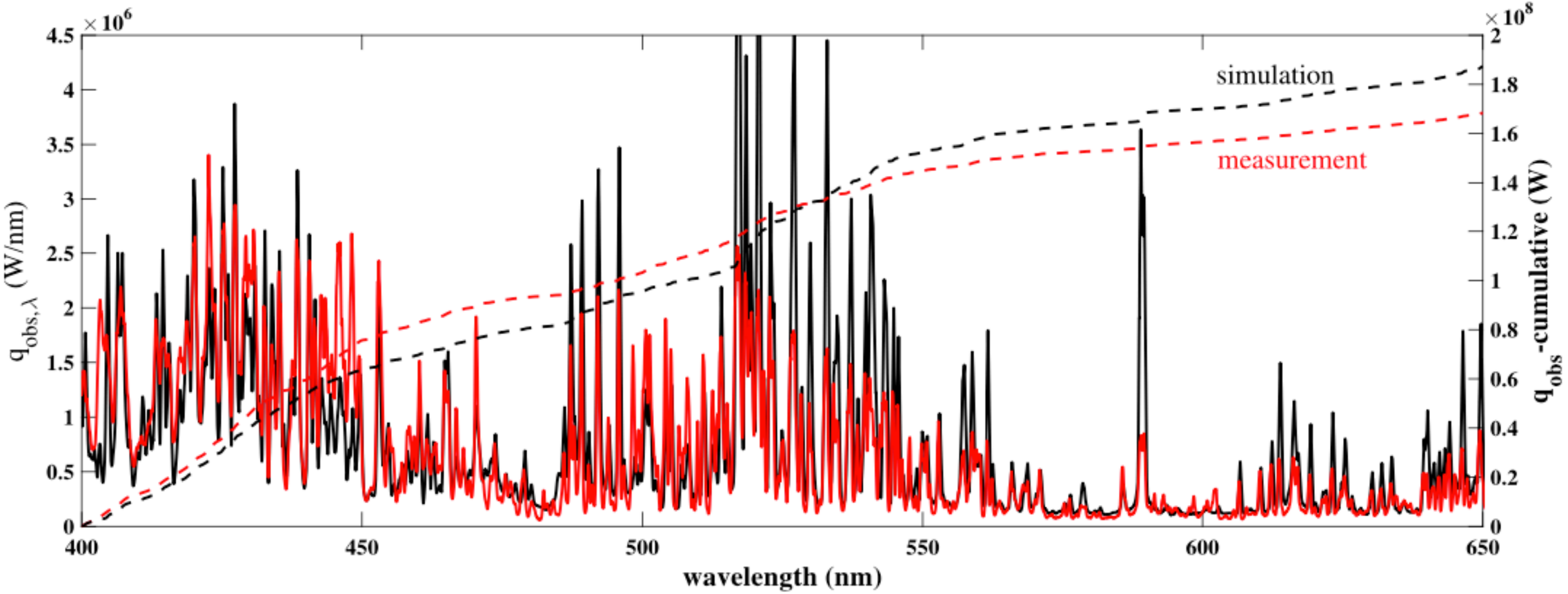


Borovicka & Spurny, 1996

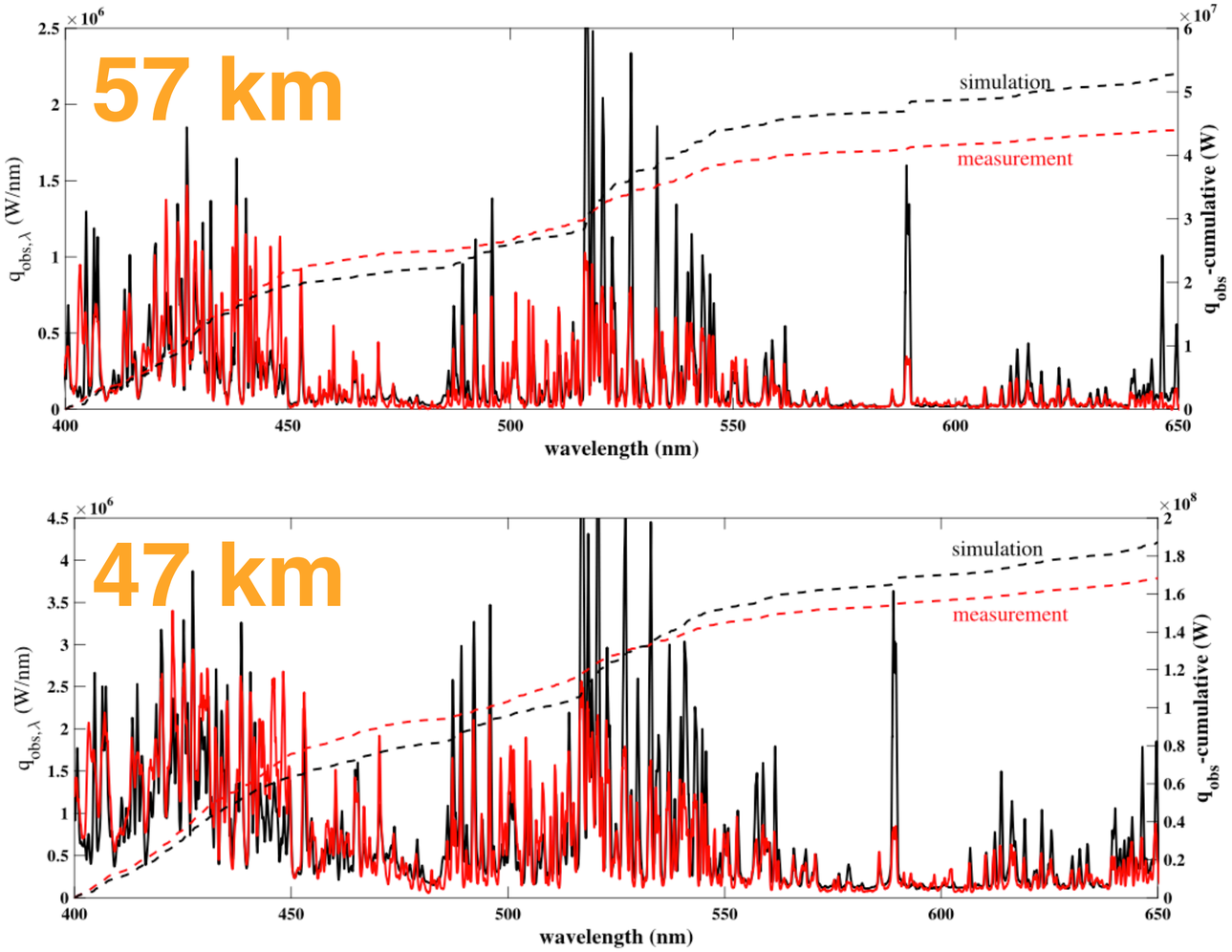
Benesov Spectrum at 57 km



Benesov Spectrum at 47km



Benesov Study Findings



- Simulated spectra able to capture most of the significant spectral features from the observation
- For both altitudes simulated, the integrated luminosity from simulation is within 30% of observed spectrum

- Based on this analysis, we have confidence that our approach could be used to improve luminous efficiency models, and thus help to better constrain inferred asteroid properties

State-of-the-Art

(The good, the promising, and the ugly)

- **Flow Modeling and Radiation ("The Good")**
  - "Tipping point" achieved in our predictive capability for radiation and luminosity
  - Modeling approach can now be applied to improving our reduced order models for meteoroid luminous efficiency
  - Can also be deployed in the design of future bolide observing campaigns
- **Ablation Modeling and Experiments ("The Promising")**
  - Significant progress has been made on high-fidelity, first principles ablation models
  - Preliminary validation studies have been performed using novel high-enthalpy experiments
  - On-going effort to synthesize this work into reduced-order models for impact risk assessments
- **Fragmentation and Break-up ("…and the Ugly")**
  - Remains the most challenging aspect of the asteroid entry problem
  - Tuned observational models, and nascent physics-based approaches do not converge
  - Current effort underway to utilize free-flight hypersonic wind tunnel experiments to aid in model development


Questions?